Ontogeny of hydric soils in created wetlands

Andrew M. Gascho Landis

Aquatic Ecology Laboratory
The Ohio State University, 1314 Kinnear Rd., Columbus, OH 43212

Introduction

Approximately 50% of presettlement wetlands in the United States have been lost to the practices of road building, agriculture, and urban and rural development (Lewis, 1995). To abate rapid wetland loss in the United States, the Clean Water Act (CWA) of 1972 allows the Army Corps of Engineers to require wetlands destroyed by development to be mitigated through wetland creation. Skepticism has arisen as to the ability of created wetlands to adequately replace naturally occurring wetlands (Malakoff, 1998). Establishing hydrophytic vegetation in a mitigation site can be a relatively easy task; however, the existence of wetland plants does not necessarily indicate that these systems are functionally equivalent to the wetlands they are intended to replicate (Craft et al., 1999). One key feature contributing to functional differences between created and natural wetlands is hydric soils, which are characteristic of natural wetlands but that take time to develope in created wetlands (Bishel-Machung et al., 1996).

Hydric soils are the physical foundation of wetland ecosystems (Stolt et al., 2000). Functions provided by wetland soils include acting as a sink for non-point source pollution ands sediments, and as a substrate for wetland plant and animal communities (Mitsch and Jørgensen, 2004). Anaerobic conditions, created by inundation, help to define the way in which nutrients cycle in wetlands, and lead to the development of hydric soil characteristics after a wetland has been created (Mitsch and Gosselink, 2000). Hydric soils are so fundamental that the United States Army Corps of Engineers requires their existence to classify an area as a jurisdictional wetland.

After wetlands have been created, monitoring is necessary to determine the success of the compensatory wetland. Assessment of plant or animal community structure is often used to measure the success of wetland creation (Cole et al., 2001). Assessing soil development is essential for determining whether created wetlands are fulfilling their functional roles (Craft et al., 2002). The period of time required for non-hydric upland soils to acquire traits characteristic of naturally occurring wetlands is unknown (Nairn and Mitsch, 1996). Soil color, bulk density and organic matter accumulation are key diagnostic features for determining the condition of wetland soils. Soil colors with a chroma of 2 or less are classified as hydric, and accumulation of organic matter in wetlands has been identified as an indicator of ecosystem maturity (Hogan et al., 2004).

The goal of this project was to contribute to a long-term study tracking soil development in two experimental wetlands at the Olentangy River Wetland Research Park (ORWRP). The first goal was to survey soil color, bulk density, and organic matter in 2004 and determine whether there were detectable differences between the two experimental wetlands. Secondly, data from 2004 were compared to historical data sets to look for the existence of trends and to determine whether the two experimental wetlands' edaphic features are tracking together through time.

Methods

Site Description

This study was conducted at the ORWRP. In 1993, two experimental wetlands were created, each one hectare in size and similar in shape. The site history includes agricultural use. The wetlands experience identical inundation levels, with water pumped in at the same volume from the Olentangy River. The main difference between the two wetlands is that Wetland one was initially planted with native hydrophytic plants and Wetland two was not planted. The goal of this experiment was to examine longer term dynamics in wetland succession and ecosystem organization. Prior to inundation the soils were classified as silty loam to clay loam, primarily in the Ross and Eldean series; these series are not representative of hydric soils.

Field Work

Soil was collected from six locations in each experimental wetland. Two samples were collected at the inflow, two samples in the middle of the wetland, and two samples near the outflow. Cores were generally extracted away from aquatic macrophytes in open wetland conditions. A soil corer was used to extract samples, which were divided into two depth categories, 0-8 cm and 8-16 cm. Examination of the two depth intervals is useful for determining the variation in wetland processes. All sampling locations had a similar water depth. Samples were taken from permanent boardwalks so as not to disturb sediments.

Soil chroma indicates whether soils have formed under reduced conditions, with chroma values of 2 or less typically indicating hydric soils (Campbell et al., 2002). Soil hue, value and chroma were determined in the field using a

Munsell Color chart immediately after extraction, while samples maintained true color without additional oxidation. After Munsell analysis, soils were placed in sealed bags and refrigerated until further laboratory work was conducted.

Laboratory Work

All soil samples were placed in an oven for 48 hours at 105º C. Drying until a constant mass was achieved ensured all water was removed before further analysis. To determine bulk density (g cm^{-3}), the mass of dried sub-samples of soil were divided by their corresponding field-moist volumes. Samples were then passed through an electric grinder with a 2mm sieve to expose maximum surface area for best percent organic matter results. Soil samples weighing approximately 10 g were placed into tared porcelain crucibles. Loss of weight on ignition at 550º C for 1 hour was used to determine percent organic matter. Inaccuracies caused by carbonates in the soil were not considered important at this research site (Nairn, 1996).

Statistics and Comparisons

Previous annual reports from the ORWRP were used to obtain historical data for comparison with soil data collected in 2004. These reports provided data collected in 1998 (Gilbert et al., 1999), 2002 (Anderson et al., 2003), and 2003 (Nahlik, unpublished data). Additionally, Nairn (1996) was used for soil data from 1993 after the wetlands were excavated but prior to inundation, and for 1995, after inundation. Data in Nairn (1996) concerning soil carbon was published as total carbon. To be comparable with all post-1995 data sets total carbon needed to be converted to organic matter. This was done using the standard conversion factor of 1.724 (Collins and Kuehl, 2001).

All comparisons were made using a two-tailed t-test. Significance was determined at p-values ≤ 0.05. T-tests compared bulk density and organic matter at both 0-8 cm and 8-16 cm depths and across depths between years 2004 and 1995. Trends were examined using data from all available years and regression analysis was performed using a ratio between organic matter and bulk density across years.

Results

Soil Color

The majority of the soil samples exhibited characteristics of hydric soil indicated by soil chroma equal to or less than 2 (Table 1). Two samples in Wetland 2 at depths of 8-16 cm had chroma greater than 2. There was an equal number of samples with a hue of 10YR and 2.5Y, with only one sample containing a hue of 5Y. Excluding one sample, soils in Wetlands 1 and 2 at the 0-8 cm depth had chroma of 1, with the exception of one sample having a chroma of 2. At this depth there was an even distribution between values of 2/1, 3/1, and 4/1. For both wetlands, depths of 8-16 cm contained a few more samples with chroma of 2 than did the 0-8 cm depth, however, half of the samples at this depth (8-16 cm) had a value of 3/1. Mottles were not abundant in the soil samples, possibly due to the fact that the cores were not collected from zones containing herbaceous vegetation, and thus little evidence existed of past or present oxidized rhizospheres.

Table 1. Munsell color chart analysis of soil samples from Wetlands 1 and 2.

Experimental Wetland	Soil Depth	Hue	Value	Chroma
1	0-8 cm	10YR	3	1
1	8-16 cm	2.5Y	3	1
1	0-8 cm	2.5Y	3	1
1	8-16 cm	2.5Y	3	2
1	0-8 cm	2.5Y	3	1
1	8-16 cm	10YR	4	2
1	0-8 cm	10YR	4	1
1	8-16 cm	10YR	4	2
1	8-16 cm	10YR	4	1
1	0-8 cm	10YR	2	1
1	8-16 cm	2.5Y	3	1
2	0-8 cm	10YR	4	1
2	8-16 cm	10YR	3	2
2	H 0-8	10YR	2	1
2	H 8-16	10YR	5	4
2	0-8 cm	10YR	3	2
2	8-16 cm	10YR	4	3
2	0-8 cm	2.5Y	3	1
2	8-16 cm	2.5Y	3	1
2	0-8 cm	2.5Y	3	1
2	8-16 cm	2.5Y	4	1
2	0-8 cm	10YR	2	1
2	8-16 cm	2.5Y	3	1

Soil Data 2004

Bulk density at the 0-8 cm depth was not significantly different between Wetlands 1 and 2 (0.84 ± 0.29 and 1.17 ± 0.35 g cm^{-3} respectively, p = 0.498). A significant difference in bulk density was discovered between the wetlands at 8-16 cm (0.96 ± 0.06 vs. 1.53 ± 0.21 g cm^{-3} respectively, p = 0.031) (Figure 1). Mean percent organic matter at 0-8 cm was 7.16 ± 0.79 % for Wetland 1 and 6.82 ± 0.57 % for Wetland 2, and at 8-16 cm depth, percent organic matter was 5.16 ± 0.21 and 5.28 ± 0.33 % for Wetlands 1 and 2 respectively. Neither of the differences between wetlands in percent organic matter were significant (p = 0.727 for 0-8 cm and p = 0.763 for 8-16 cm) (Figure 2).

Cumulative Soil Data

Comparing bulk density data between 1995 and 2004, Wetlands 1 and 2 combined have changed significantly at both depth intervals (p = 0.000) (Figure 3). However, when the wetlands were examined individually across this time interval, Wetland 1 showed no significant difference at either the 0-8 or the 8-16 cm depths (p = 0.466 and 0.364, respectively). In contrast, there was a significant difference between 1995 and 2004 at both depth intervals in Wetland 2. Percent organic matter for Wetlands 1 and 2 combined at both soil depths showed a significant increase

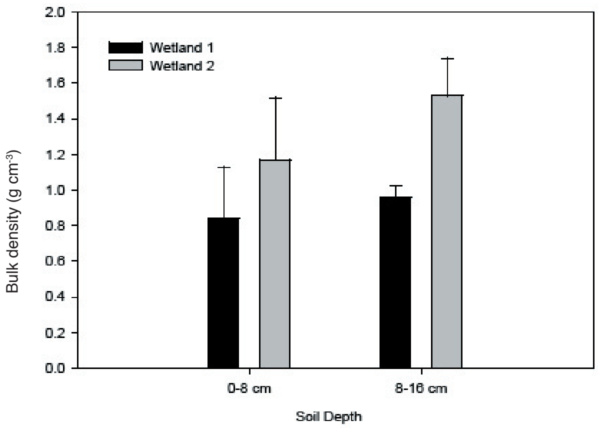

Figure 1. Mean bulk densities (g cm^{-3}) for two experimental wetlands at the Olentangy River Wetlands Research Park for 2004, at 0-8 and 8-16 cm depths.

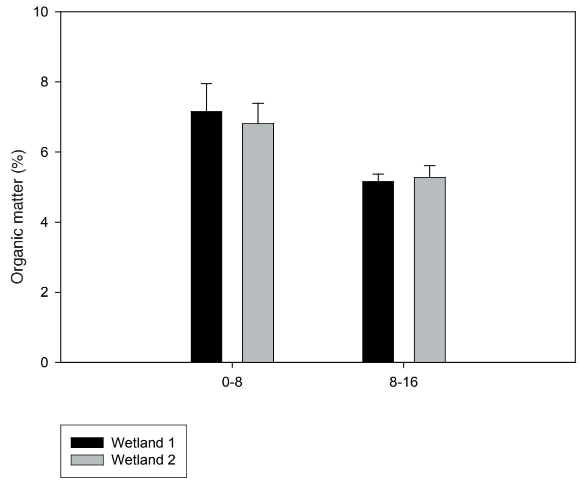

Figure 2. Percent organic matter for two experimental wetlands at the Olentangy River Wetlands Research Park for 2004, at 0-8 and 8-16 cm depths.

from 1995 to 2004 (p = 0.000). This remained true when organic matter data was examined on an individual wetland basis at each depth.

Examining bulk density and percent organic matter of several historical data sets combined revealed some interesting trends (Figure 3). Bulk density from pre-inundation to the present has varied relatively little over the entire soil profile (0-16 cm). Significant differences can be detected at various depths in some years, however there does not appear to be a consistent pattern. Percent organic matter has increased since before inundation, with the most dramatic rises occurring between 1998 and 2002. After this increase, organic matter accumulation appeared to decrease between 2003 and 2004.

To further assess the relationship between percent organic matter and bulk density, a ratio was developed between the two variables by dividing bulk density by organic matter. Data for the two variables were combined across experimental wetlands and soil depths. This ratio was then plotted against its corresponding calendar year to create a model of bulk density and organic matter development through time after wetland creation (Figure 4). This model shows a significant increasing trend between the ratio of organic matter, bulk density and time with an R^2 value of 0.68 (p = 0.04).

Discussion

Soil Color

Soil colors in 2004 in the experimental wetlands were indicative of hydric soils. Since initial measurements in 1995, there has been a decrease in soil chroma to values that correspond well to the increase of organic matter measured in the wetlands. Two samples in Wetland 2 exhibited non-hydric soil colors at lower depths. These differences may be driven by heterogeneity of fine scale variation in redox potential, soil permeability, or mineral concentrations.

Soil Data 2004

Soil characteristics are key parameters in the ongoing experiment in self-design at the ORWRP (Mitsch and Wilson, 1996). Differences in soil characteristics between the wetlands could be indicative of alternative pathways of self-design driven by plant community dynamics in the planted and unplanted wetlands. Percent organic matter is related to herbaceous vegetation inputs. In 2004, there were no significant differences in percent organic matter between the wetlands. This is indicative of similar amounts and quality of plant matter input into the wetlands (Collins and Keuhl, 2001), which is consistent with the fact that in recent years no significant difference has been found in net primary productivity between the two wetlands (Mitsch et al., 2001). The relatively even inputs of herbaceous material should have a trickle down effect on soil bulk density; it has been shown that as percent organic matter increases, there is a corresponding decrease in bulk density (Collins and Keuhl, 2001). In 1993, no significant differences in bulk density existed between wetland sites (Nairn, 1996). In 2004, however, a difference in bulk density was found between the wetlands at the 8-16 cm depth. This is most likely linked to sampling artifacts in Wetland 2. Two cores were extracted that contained non-hydric, mineral soil, and these samples biased the mean toward a higher bulk density. This disparity aside, soil characteristics indicate that ecosystem development is comparable between the two experimental wetlands.

Cumulative Soil Data

The initiation of a hydrologic regime with the creation of the two experimental wetlands has led to the development of hydric soils, as expected. One expectation of this soil ontogeny is for the percent organic matter to increase, and for bulk density to correspondingly decrease. Typically, this decrease occurs most rapidly in the upper soil layer, which accumulates sediments and incorporates organic matter more readily. Decreases in bulk density also occur at lower soil depths, but at a slower rate. Results reported here indicate that bulk density measurements have varied on an annual basis since wetland creation, with no definite trend of increasing or decreasing (Figure 3). Often, wetland creation and restoration are given a relatively short period of time in which to match projected outcomes, which can be unrealistic (Mitsch et al., 1996). However, wetland restoration and creation can require a substantial amount of time before soil characteristics (or other features) become equivalents to their natural counterparts. The short period of time that often elapses before evaluation of created

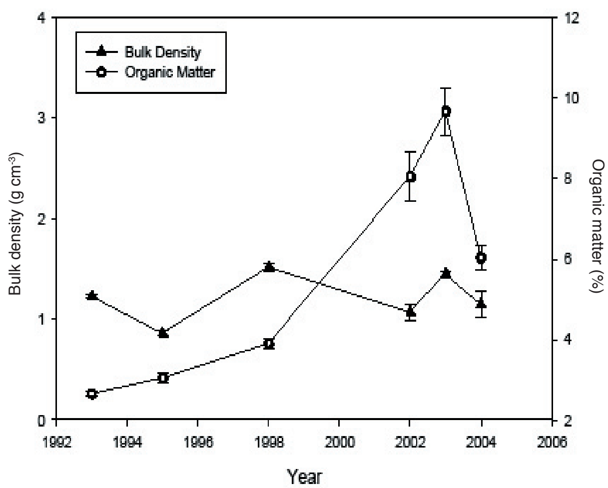

Figure 3. Trends from 1993 (pre-inundation) to 2004 comparing bulk density and percent organic matter.

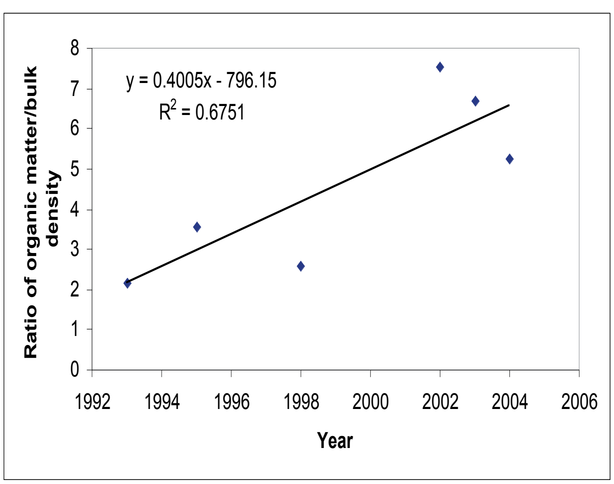

Figure 4. The ratio of percent organic matter to mean bulk density over time, across wetlands and soil depths.

wetlands results in many created wetlands being judged as failures (Malakoff, 1998).

At the Olentangy River Wetlands, percent organic matter has increased significantly over time. Levels of organic matter at the experimental wetlands are beginning to match those reported in the literature for reference or natural freshwater marshes. A study in Pennsylvania determined that organic matter in the surface soils of a reference marsh were 11.5% and 4.8% on average in created wetlands (Campbell et al., 2002). In past studies, the average percent organic matter for the Olentangy River Wetlands has been 9.7, aligning much more closely with levels of organic matter found in natural systems (Campbell et al., 2002). Bulk density in 10 year old created wetlands in Florida was 1.0 g cm^{-3} (Nair et al., 1999), values close to those observed at the Olentangy River Wetlands. However, this value is higher than bulk densities observed in older created wetlands and natural freshwater marshes, which are approximately 0.6 ± 0.2 (Nair et al., 1999; Campbell et al., 2002). One potential reason that bulk density has remained high despite the increase in organic matter may be the land use history at this site. Bruland et al. (2003) attributed high bulk densities at a wetland creation complex in North Carolina to a history of clearing, draining, and plowing. Additionally, higher bulk densities may be due to compaction caused by the excavation equipment used during wetland construction. Ultimately, it is difficult to gauge whether current bulk density at the Olentangy River Wetlands is within a normal range, because the natural variability in bulk density is high due to the heterogeneity of parent material found in a localized area.

Percent soil organic matter in 2004 was lower than in the previous two years. This may be linked to several factors. First, it may simply be related to differences in laboratory techniques. Secondly, Anderson et al. (2003) sampled only in areas dominated with vegetation cover of *Schoenoplectus tabernaemontani*. Extraction of soil cores in 2004 was conducted in areas lacking macrophyte cover, which may account for a decrease in percent organic matter due to less input. The relatively small sample size used in this study and in Anderson et al. (2003) could also lend to exaggerated variation between years.

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